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(12) **EUROPEAN PATENT APPLICATION**

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(54) **System comprising Er-doped optical fiber.**

(57) The inventive optical fiber communication system comprises Si-based amplifier fiber whose core comprises Ge(23,25), Al(26), and Er(24). The amplifier fiber has an effective index difference ($\Delta n$) greater than 0.03, an effective core diameter $\underline{a}$ less than 3.5μm, a maximum Al concentration in the core of at least 6 mole %, a mode field diameter at the pump wavelength that is less than 5 μm, a V-number at the pump wavelength in the range 1.4-2.0, a cut-off wavelength less than 1.4μm, and an Er distribution whose effective diameter is less than that of the Ge distribution. The fiber has advantageous properties including low amplificiation threshold and noise. Disclosed is also a method of making optical fiber that can be used to produce fiber having characteristics (e.g., $\Delta n > 0.03$, high Al concentration) not generally obtainable with prior art methods. In a particular embodiment the method comprises a partial collapse of a tubular preform prior to completion of core material deposition, and final collapse.

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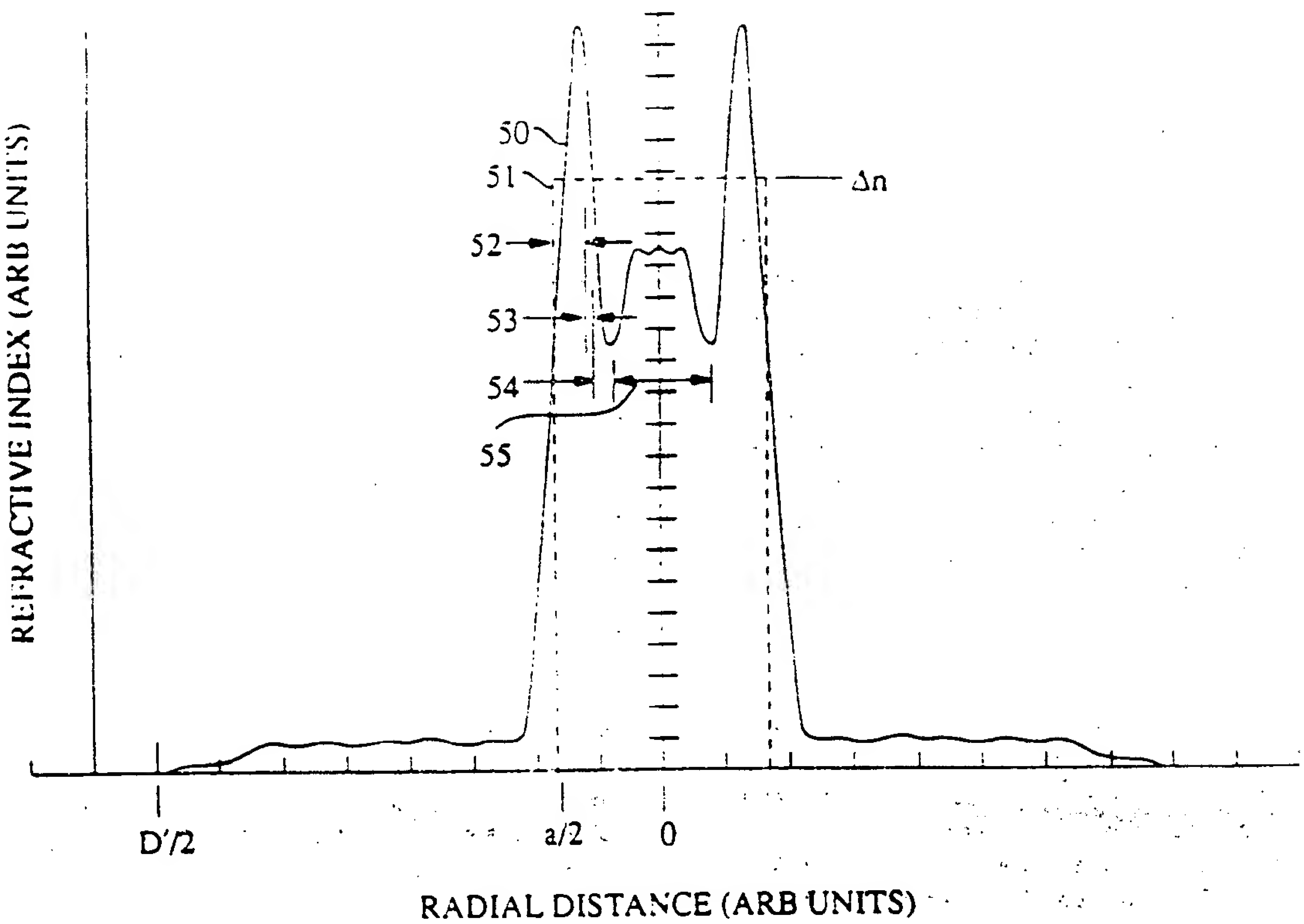
FIG. 5



REFRACTIVE INDEX (ARB UNITS)
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Δn
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RADIAL DISTANCE (ARB UNITS)

## Field of the Invention

This invention pertains to systems, exemplarily optical fiber communication systems, that comprise an optical fiber amplifier. The optical fibers of concern herein are $SiO_2$-based Er-doped optical fibers.

## Background of the Invention

It has been known for some time that rare-earth ion doped glasses in fiber form could be used as a lasing medium. However, it has only been recently that the possibility of using such fiber as the amplification medium in an optical fiber communication system has begun to be explored seriously. Most interest is currently directed towards fiber that comprises $Er^{3+}$ ions. Among possible pump wavelengths ($\lambda_p$) are those in the 0.8-1.0 μm range (e.g., 0.98 μm) and those relatively close to (but below) the anticipated signal radiation wavelength ($\lambda_m$) of about 1.5 μm (e.g., 1.48 μm).

The principle of amplification of an optical signal in an Er-doped fiber amplifier (EDFA) is known to those skilled in the art. See, for instance, J. R. Armitage, Applied Optics, Vol. 27(23), pp. 4831-4836, Dec. 1988. However, in order to be of commercial interest, a fiber design has to be found that has certain desirable characteristics. Among these typically are high efficiency, low noise, low loss and acceptable mechanical properties (e.g., strength).

Several design criteria are known to those skilled in the art. For instance, J. R. Armitage (op. cit.) teaches that

i) the fundamental pump mode ($LP_{01}$) is the optimum mode with which to pump the EDFA; and
ii) the preferred dopant (i.e., $Er^{3+}$) profile is one in which the dopant ions are confined just to the central region of the fiber core.

That author also states that, for a given form of the Er-profile, there exists a core size with which to achieve maximum amplification. Generally the optimum core provides for maximum overlap of the pump and signal radiation modes. Cores having effective diameter a and effective refractive index difference Δn (to be defined below) that result in a V-number at $\lambda_p$ of approximately 3 were stated to be optimal for use in a high gain EDFA.

However, even though at least some design criteria are known, in the design of an actual fiber amplifier trade-offs are frequently necessary. For instance, in practice it may not be possible to produce fiber that meets all the criteria. J. R. Armitage (op. cit.) states as follows: "In practice, control of the dopant profile, particularly for small core sizes, may prove to be difficult due to problems of dopant ion diffusion during the fiber making process. This may then impose a practical limit on how near to optimum it is possible to produce a real fiber."

It is known that $SiO_2$-based fibers with an $Al_2O_3$-$GeO_2$-$SiO_2$ core can advantageously be used as the amplifier fiber for EDFA, with the presence of Al considered to contribute to high efficiency of the amplification process. See U.S. patent 4,923,279 to B. J. Ainslie et al. which discloses a silica-based EDFA fiber with refractive index difference 0.01 and with a core of overall diameter 4 μm. The core consisted of an inner, Er-doped core region of diameter 1.5 μm which also contained Si, P and Al, and an outer region that contained Si, Ge, and P. The deposited cladding of the fiber contained Si, P and F, with the P and F concentrations chosen such that the material had a refractive index equal to that of pure fused silica. The Al and Er distributions were apparently co-extensive. The fiber apparently was designed for relatively short $\lambda_p$ (528.7 nm) and apparently was not single mode at $\lambda_p$.

Even though some general design principles are known for EDFA fibers, the prior art does not contain a design for low noise fibers of high efficiency and low amplification threshold. In view of the general importance of these characteristics and, in particular, their importance for a remotely pumped EDFA, it would be highly desirable to have available such designs, and in particular such designs that are manufacturable. Furthermore, it would be higtily desirable to have available methods of making fiber that make it possible to attain previously unattainable parameter values. This application discloses both such designs and such methods.

## Glossary and Definitions

An "optical fiber" is an elongate body adapted for longitudinally guiding therethrough electromagnetic radiation of a predetermined wavelength. It comprises a central region of relatively high refractive index (the core) contactingly surrounded by a region of relatively low refractive index (the cladding).

A "single mode" optical fiber is an optical fiber designed to transmit with low loss only a single mode of radiation of the predetermined wavelength. Of course, a fiber that is a single mode fiber at one wavelength may not be a single mode fiber at another (shorter) wavelength.

A "vapor deposition process" herein is a process that comprises reacting a mixture of precursor gases (e.g., $SiCl_4$ and $O_2$ or $SiCl_4$, $GeCl_4$ and $O_2$) such that $SiO_2$-based reaction product is deposited on a substrate.

An "inside" vapor deposition process herein is a vapor deposition process comprising reacting the precursor gases within a "substrate" tube (generally a $SiO_2$ tube), and causing deposition of the reaction product on the inside of the substrate tube. MCVD is an exemplary inside vapor deposition process.

A "preform" herein is a silica-based elongate glass body of, generally, circular cross section that

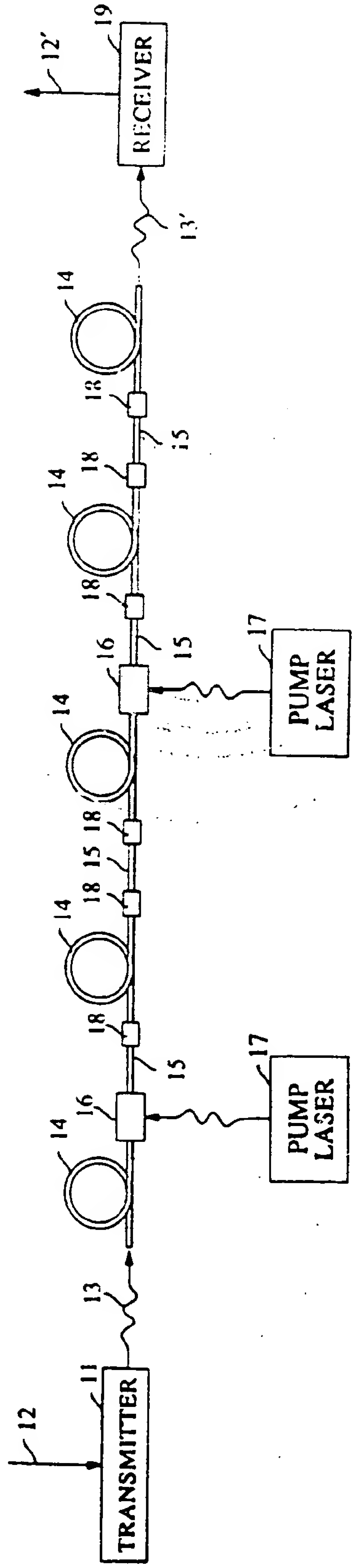
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FIG. 1

FIG. 2

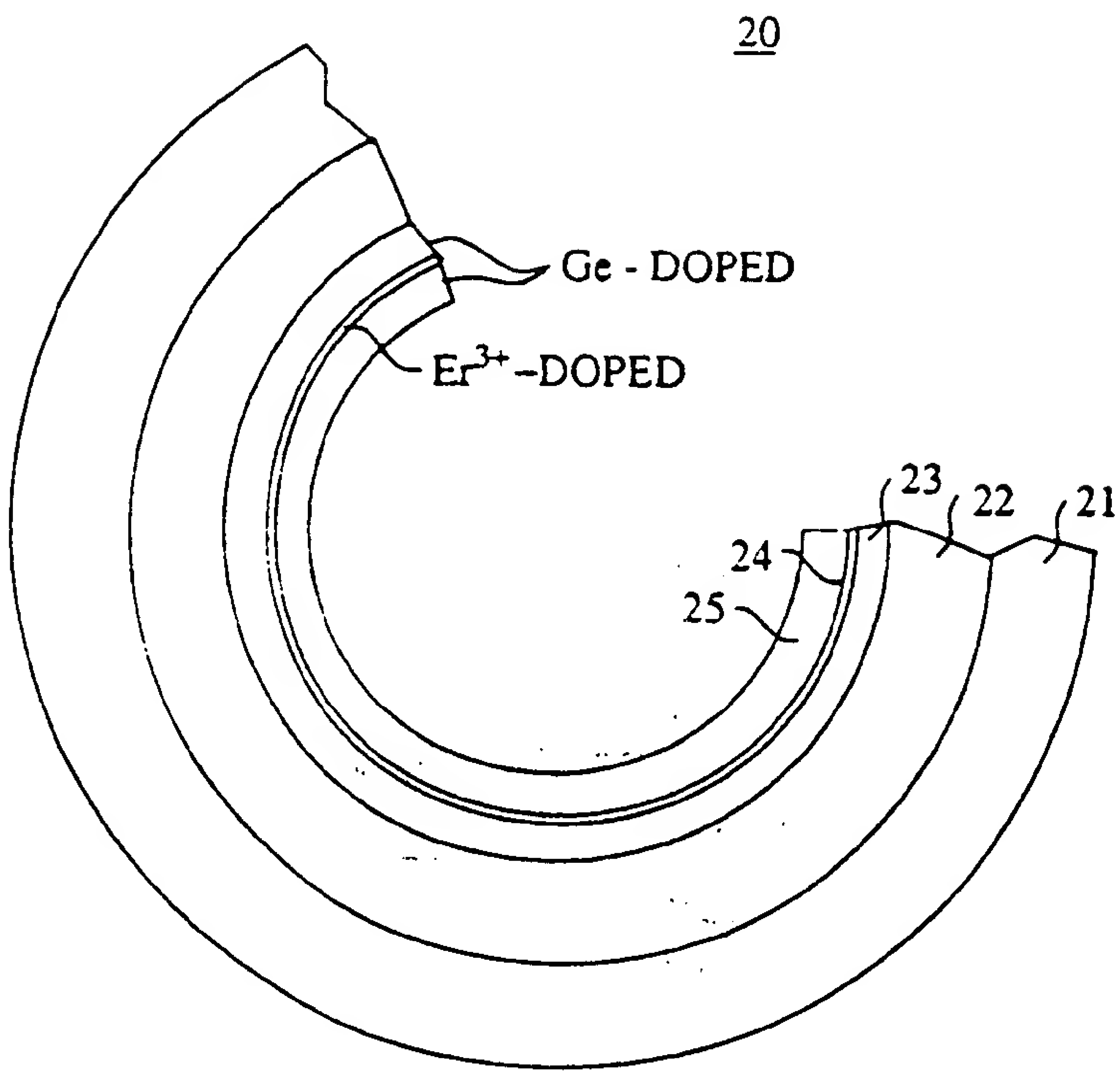



FIG. 3

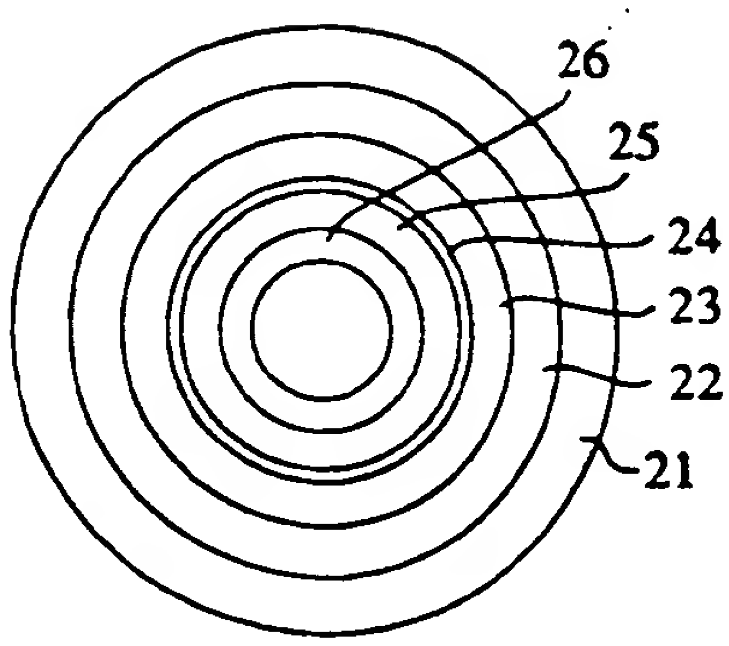



FIG. 4

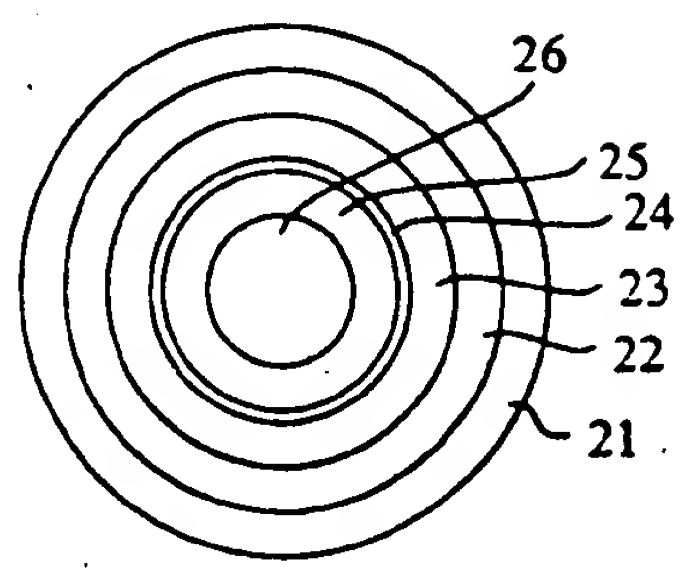
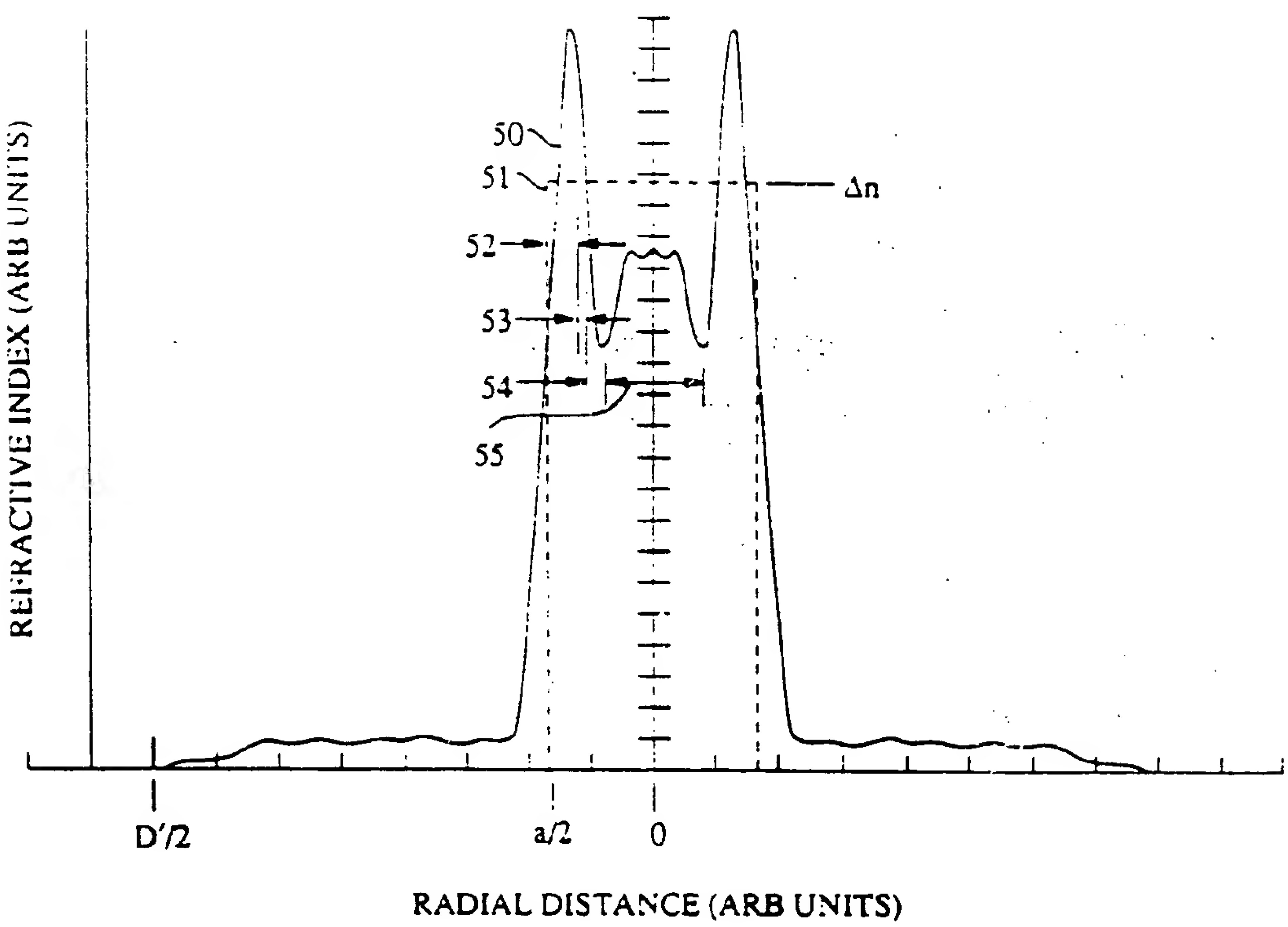


FIG. 5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RADIAL DISTANCE (ARB UNITS)

European Patent Office

# EUROPEAN SEARCH REPORT

Application Number

EP 91 30 6816

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int. Cl.5) |
|---|---|---|---|
| P,X | EP-A-0 437 935 (AMERICAN TELEPHONE AND TELEGRAPH COMPANY) * tables 1,3; page 55; figure 14 * --- | 1,3,4,6,8 | H 01 S 3/06 |
| A,D | US-A-4 923 279 (B.J. ANISHI et al.) * column 4, line 39 - column 5, line 25; claims 16-21 * --- | 1-3,5 | |
| A | DATABASE WPIL accession no. 87-181556, week 8726, Derwent Publications Ltd., London, GB; & JP - A - 62111208 (NTT) 22.05.1987 * whole document * --- | 1 | |
| A | ELECTRONICS LETTERS vol. 26, no. 15, 19 July 1990, pages 1149-1151, Stevenage, Herts., GB; K. SMITH et al.: "Erbium fibre soliton laser" * page 1150, paragraph 1 * --- | 1,4 | |
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| A | ELECTRONIC LETTERS vol. 26, no. 14, 5 July 1990, pages 1032-1034, Stevenage, Herts., GB; SUZUKI et al.: "Automatic optical soliton control using cascaded Er 3+-doped fibre amplifiers" * figure 1 * ----- | 7 | |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| BERLIN | 08-11-1991 | VON MOERS F |

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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& : member of the same patent family, corresponding document

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